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Tilt Table – Design Manual

Prepared for
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Transport Canada

by
Centre de recherche industrielle du Québec

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**TILT TABLE
DESIGN MANUAL**

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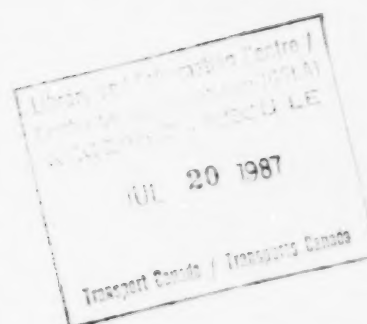
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The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre.

Un sommaire en français de ce rapport est inclus avant la table des matières.

Ce document est également disponible en français: "Table de renversement - Manuel de conception", TP 7523F.

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17. Abstract			
A tilt table has been designed, built and installed for Transport Canada. This test equipment is basically a laterally tilting platform on which heavy vehicles are driven and inclined in order to determine their rollover threshold. This report describes the design of the structure, the hydraulic and electrical systems and the weighing pads. The load limits of the table and the weighing pads are provided along with a list of drawings. Finally, recommendations are made for the design of future tilt tables.			
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17. Résumé Une table de renversement a été conçue, construite et mise sur pied pour Transports Canada. Cet équipement d'essai est essentiellement une plate-forme inclinable latéralement sur laquelle montent les véhicules lourds afin de déterminer leur seuil de renversement. Ce rapport explique la conception de la structure, des systèmes hydraulique et électrique et des plateaux de mesure. Les capacités de la table elle-même et des plateaux de mesure y sont données de même que la liste complète des dessins. Finalement, certaines recommandations sont présentées en vue de la construction éventuelle de nouvelles tables de renversement.			
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SUMMARY

This report describes a tilt table designed and built for Transport Canada. This table is a test apparatus basically composed of a laterally tilting platform on which heavy trucks are driven and tilted in order to determine their rollover threshold.

The welded structure has been designed to accept all the heavy trucks currently allowed to run on Canadian roads. In order to make it easily movable, the table has two sections 12.2 m long by only 4.3 m wide. Each section comprises one base supported by a series of adjustable supports and one platform tilting laterally up to 35 degrees.

Each platform is tilted by two synchronized hydraulic cylinders; the hydraulic pump is driven by an internal combustion engine which makes the unit self sufficient. The electrical circuit comprises, in addition to the basic elements, a series of switches acting on the hydraulic valves in order to maintain the synchronisation of the four hydraulic cylinders.

Our experience with this table during the first series of tilt tests has demonstrated that it met the specifications. However, if new tables are to be built, it is recommended that the design be re-evaluated in order to further improve the tilt table.

SOMMAIRE

Le présent rapport décrit la conception d'une table de renversement conçue et construite pour Transports Canada. Cette table est un appareil d'essai constitué essentiellement d'une plate-forme inclinable latéralement sur laquelle montent les camions lourds afin de déterminer leur seuil de renversement.

La structure métallique soudée a été prévue pour accepter tous les camions lourds admis à circuler sur nos routes. Dans le but de la rendre facilement déménageable, elle se compose de deux sections de 12,2 m de longueur par seulement 4,3 m de largeur. Chaque section comprend une base supportée par des pieds ajustables et une plate-forme inclinable latéralement jusqu'à 35 degrés.

Chaque demi-plate-forme est actionnée par deux vérins hydrauliques synchronisés; la pompe hydraulique est entraînée par un moteur à combustion interne afin de rendre l'ensemble autonome. Le circuit électrique comprend, en plus des éléments courants, un ensemble d'interrupteurs agissant sur les électrovalves hydrauliques et servant à maintenir la bonne synchronisation des quatre vérins.

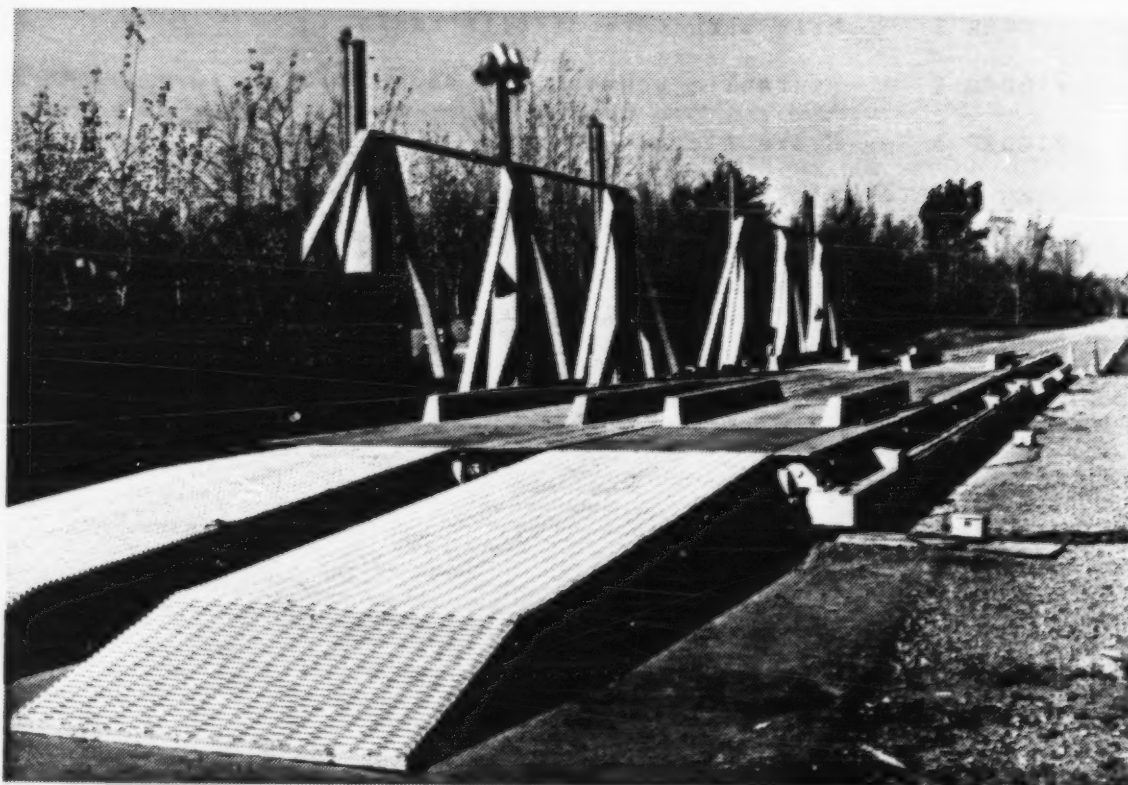
Notre expérience avec cette table lors des premiers essais de renversement a démontré que celle-ci répondait bien aux exigences; cependant, si l'on devait construire de nouvelles tables, il est recommandé de réévaluer certains aspects du concept afin d'améliorer le fonctionnement de cette table.

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TILT TABLE

1.0 GENERAL DESCRIPTION

1.1 Design of the tilt table

A tilt table is a test apparatus designed to measure vehicle rollover threshold, specially that of heavy trucks and buses. Essentially it is a laterally tiltable platform on which the test vehicle is driven; this platform is then tilted until one or more wheels lose contact with the platform. The tilting of the vehicle simulates the lateral acceleration it encounters when negotiating a level curve at constant speed. The only difference is found in the forces perpendicular to the ground, which remain constant in a curve, but diminish as a function of the cosine of the tilt angle on a tilt table. As most heavy vehicles rollover at angles of less than 25 degrees, this reduction in perpendicular loads is less than 10%. This causes very little suspension spring back and the height of the centre of gravity does not change significantly. The lateral acceleration simulated by the table can therefore be said to be representative of the lateral acceleration a vehicle will experience in a level curve at constant speed.

The tilt table designed for Transport Canada is easily movable and can be installed on any reasonably level and strong surface to allow heavy vehicle traffic.

The table is of modular construction; it is composed of two similar sections, each having a base and a tilting platform. The base has twelve adjustable supports for easy leveling of the platform on irregular ground. Each platform is pivoted about one side of the base by two synchronized cylinders. Four access ramps, two at each end, allow driving the vehicle on and off the table on its own power. The two tire running strips have recesses for the installation of weighing pads at any place along the table. Actually, there are five weighing pads available; when tilt testing a typical truck and trailer combination, two are installed under the trailer wheel group, two under the tractor rear wheel group and one is placed under one wheel of the front axle.

A hydraulic group, driven by a diesel engine and some electrical controls, complete the tilt table. Figures 1 and 2 show the complete tilt table ready for tilt tests.

It will be possible in the future to extend the table by adding one or more sections and/or to increase the number of weighing pads.

1.2 General specifications

1.2.1 DIMENSIONS

Overall length	- 33.6 m (110 ft)
Overall width	- 4.3 m (14 ft)
Overall height (lowered)	- 3.25 m (128 in.)
Overall height (fully raised)	- 24.4 m (80 ft)
Track width	- up to 2.9 m (114 in.)
Height of the platform from ground	- min. 42.2 cm (16.6 in.) max. 54.6 cm (21.5 in.)
Maximum tilt angle	- 35 degrees

1.2.2 HYDRAULIC SYSTEM

Engine	- diesel 60 HP
Pump	- piston type, flow compensated 113 l/min at 13.8 MPa, 1800 rpm (30 GPM at 2000 psi, 1800 rpm)
Oil reservoir	- 200 litres
Fuel reservoir	- 100 litres
Cylinders	- 12.7 cm (5 in.) diameter 236.2 cm (93 in.) stroke distance between pivots: 30.5 cm (12 in.) closed 266.7 cm (105 in.) open maximum press.: 13.8 MPa (2000 psi)

1.2.3 OPERATING CHARACTERISTICS

Maximum total load	- 135 000 kg (see note)
Maximum axle load	- 12 000 kg (25 000 lb)
Tilting speed	- adjustable from 15 to 30 degrees/minute
Lowering speed	- adjustable at about 15 degrees/minute and less; depends on oil temperature and load.

Cylinder synchronization- by rotary flow divider plus a correction system based on the level of each platform and the difference in height between platforms.

Maximum variation of the
local tilt angle - 0.5 degree
Maximum longitudinal
inclinaison - 7.6 cm on 12.2 m
(3 in. on 40 ft)

NOTE: The maximum load on each platform depends where it is applied longitudinally; figure A1 gives the maximum acceptable resultant load as a function of its position.

2.0 STRUCTURE

2.1 Structural design

Each module of the tilt table comprises a base and an inclinable platform. The base is reinforced by the addition of an I beam on the pivot side to support a greater share of the total load. On the cylinder side, the base sees only two concentrated loads at the two cylinder attachment points. Two supports have been placed on each side of these cylinder pivots to transmit the load directly to ground. There is a total of 12 supports on each base, 7 on the cylinder side and 5 on the pivot side.

The structure of each platform is composed of two series of beams for longitudinal and transversal stiffness. Longitudinally, stiffness is provided by two sub-structures. On the pivot side, a Z beam formed by the welding of two large angles is joined to the base by 5 pivots to form a stiff member supported by 5 supports. On the cylinder side, a series of welded tubes forms a stiff wall. Twelve transversal H beams join the two side members. This structure is quite flexible in torsion, therefore preventing excessive stresses when the cylinders lose synchronization. Figure 3 shows the basic structure of a platform.

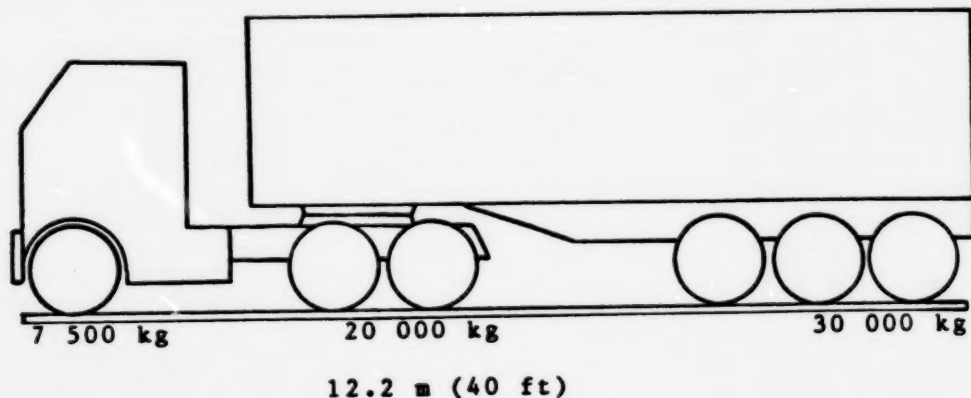
2.2 Load cases

Various legal truck and axle configurations were examined in order to determine endurance of the table and its accessories.

In Canada, legislation limits vehicle loads according to two criteria, gross vehicle weight (GVW) and gross axle weight (GAW). For a typical truck trailer, the maximum legal gross vehicle weight is 57 500 kg. When the axle spacing is larger than specified minimums, the maximum gross axle weight goes as high as 10 000 kg per axle with dual tires.

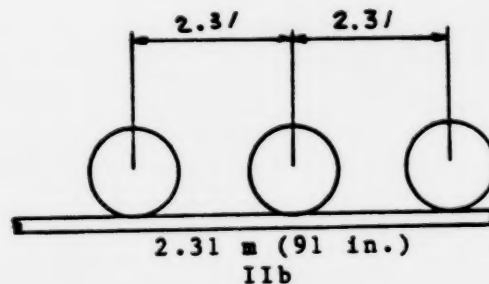
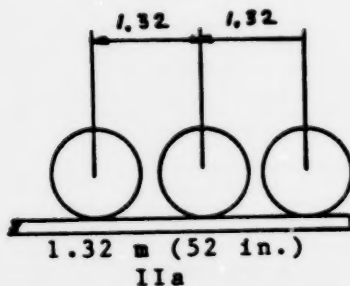
As the first load case, we considered a semi-trailer with a GVW of 57 500 kg which is short enough to fit on one platform only. The load on the front axle was 7 500 kg; the one on the tractor rear axles, 20 000 kg;

and the three-axle group on the trailer supported 30 000 kg. Axle spacing was set at only 1.2 m, which would be illegal for this load. This vehicle is represented in the following sketch:



LOAD CASE I

The second load case was a three-axle group loaded with 30 000 kg, placed very close to the end of the platform and being the only load on the platform. Two axle spacings were considered, 1.32 m and 2.31 m.



LOAD CASE II

For the last load case, we evaluated the stresses in the structure when a platform loaded with the short truck of load case I is supported by cylinders having a difference in length of 15 cm (6 in.).

2.3 Static analysis

Results of the finite element analysis are presented in CRIQ technical report no PRT-85-068 (ref. 1).

It is difficult to summarize all the results in a few lines, but it is interesting to note the maximum stresses calculated for the various load cases.

Load case I	(57 500 kg truck)	18 500 psi
Load case IIa	(3 axles, 30 000 kg, 1.32 m)	22 800 psi
Load case IIb	(3 axles, 30 000 kg, 2.31 m)	19 700 psi
Load case III	(57 500 kg truck + torsion)	18 800 psi*

These stresses provide a safety factor of 1.9 with respect to the elastic limit of the material used.

The table was stress-tested by installing ten strain gauges at locations where finite element analysis showed the highest stresses. With tandem axles loaded with 23 500 kg and placed at various positions along the platform, maximum stresses of 9 060 psi were noted. With a load of 30 000 kg, stresses would have reached only 11 565 psi compared to an assessment of over 20 000. This proves that the model was on the safe side and that the neglected plates and reinforcements take their share of the load and relieve the stresses in the main parts.

2.4 Dynamic analysis

The dynamic behaviour of the tilt table was also studied with a finite element mathematical model.

First, the natural frequencies of the table were calculated with no load on the platform. The results for the first six vibration modes gave frequencies of 15.1, 15.9, 16.4, 20.0, 26.2 and 27.0 Hz. These frequencies, being all much higher than those expected on a vehicle, indicated that the table should not demonstrate any resonance problems.

In a second analysis, the natural frequencies were calculated for the table with a typical truck rigidly attached to one platform. Results were frequencies of 5.4, 5.7, 6.3, 6.9, 7.9 and 11.1 Hz. These frequencies are still quite high when compared to the natural frequencies of truck tires and suspensions but it was not considered realistic to rigidly attach the mass of the truck to the platform. The motion of suspensions

- 6 -

*Calculations have shown stresses up to 32 000 psi at the base of the U-shaped column around the cylinders. However, the model for this area does not take into account the reinforcing plates which prevent the bending around the cylinder support, thereby diminishing the stresses in this area.

isolates the mass of the truck from the platform, thus allowing the latter to vibrate more freely.

To better study the dynamic behavior of the table, a truck was roughly simulated by attaching equivalent masses to the table with springs. These springs and masses represented a typical truck supported by a total of only three axles. The first vibration modes for this system were at much lower frequencies: 1.2, 1.6, 1.7, 2.6, 2.9 and 6.6 Hz, but they corresponded to the natural frequencies of the truck and not of the table because displacements for these frequencies were mostly truck oscillations. This confirms that during dynamic tests, it will be possible to excite the natural frequencies of the vehicle without having table resonance.

With the stresses calculated for the dynamic analysis, the structure of one platform can support an estimated dynamic load of 85 000 kg (187 600 lb). This means it will be possible to give an acceleration of 0.47 G to a 57 500 kg (126 600 lb) truck. CRIQ report PRT-85-068 (ref. 1) gives more details on this dynamic analysis.

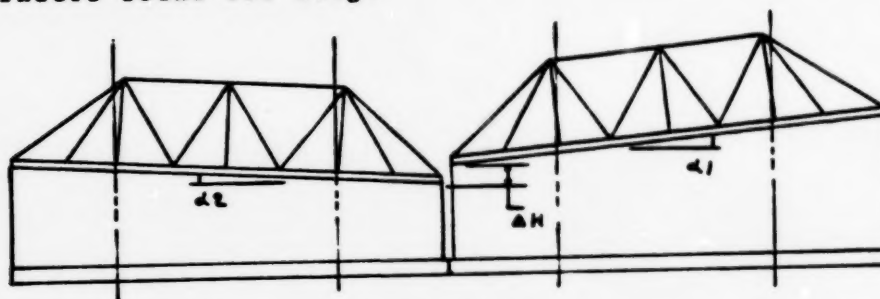
3.0 HYDRAULIC SYSTEM

3.1 Principle of operation

Operation of the tilt table is based on the synchronized motion of the four hydraulic cylinders. In fact, if one wants to submit each part of a vehicle to the same lateral acceleration, the surfaces holding all the axles must be in the same plane with a uniform tilt angle.

As it was impossible to build a platform rigid enough in torsion to assure a uniform tilt angle, it was decided that the position of each platform would be controlled by the length of each cylinder.

The synchronization of each cylinder is done through the use of two complementary systems. A gear flow divider makes the first division of the oil going to each cylinder. A second system constantly checks the level of both platforms ($\alpha 1$ and $\alpha 2$) and the difference in height between the two platforms (ΔH); it corrects by lowering cylinders found too long.



The schematic diagram of the hydraulic system is given in figure 4. It is shown that the oil goes through the flow divider when raising and lowering the table. Most often, the pressures at each cylinder are approximately equal and the flow divider works well as its precision depends then only on its physical internal dimensions. However, when the cylinder pressures differ, the efficiency of each gear set, working as a pump or as a motor, gets different and the flow out of each section can differ by as much as 10 to 15%. This is why a correction circuit is needed.

The complementary correction circuit drains some oil from the cylinders found longer than the others until they all come back to the same length. If we look at the hydraulic schematic diagram of figure 4 and at the electrical schematic diagram of figure 5, we can see that if

platform no 1 for example, leans on the left because cylinder no 1 is longer than cylinder no 2, switch no 1 closes and energizes the equalization valve EQ1. Oil from cylinder no 1 flows to drain and cylinder no 1 retracts, thus correcting the level of platform no 1. Each platform has one level correction circuit and at the center of the table, the double acting switch S5 detects the difference in height between the two platforms; S5 acts on the two cylinders of the platform detected too high.

A series of auxiliary switches are actuated when the lack of level of each platform or the difference of height between platforms get too large. These switches operate an alarm indicating to the operator that the correction system cannot maintain the platforms within the established limits and advise him to stop the motion of the table to leave more time to the system to apply corrections. If alarm persists, the operator must identify the problem and correct it.

The correction flows are adjustable; they must be large enough to correct quickly the lack of cylinder synchronization but without inducing platform oscillations. On the other hand, if they are too small, chances are the alarm will go on more often.

When the loads are well distributed on the platforms, the pressures in all the cylinders are approximatively the same and the flow divider works properly. Under these conditions, there are few corrections during the raising or lowering of the table; this is an ideal operation which one should aim to, because the tilting of the platform is more uniform.

3.2 Calculation of the main components

3.2.1 CALCULATION OF THE CYLINDERS

Specifications asked for a total load of 91 000 kg (200 000 lb) for both platforms; 45 500 kg (100 000 lb) per platform. When the load is well distributed, the requirement is only 22 750 kg per cylinder. Considering the loads on the table are axle groups located anywhere along the table, the worst condition for one cylinder is when this axle group is close to the end of the platform. At this position, the cylinder must take all the load and a greater share of the platform weight.

Calculations show that 12.7 cm (5 in.) diameter cylinders would be enough to lift the specified maximum loads with a maximum pressure of 13.8 MPa (2 000 psi).

Experimental pressure measurements in one cylinder, for two different loads and in many positions along the platform, were used to establish the maximum value of the resultant of all the loads on one platform. This limit follows two criteria:

- maximum pressure in a cylinder limited to 13.8 MPa;
- no negative pressure in the other cylinder.

Experimental results are presented in appendix A and the curve determining the maximum load is given in figure 8.

3.2.2 DETERMINATION OF THE PUMP CAPACITY

The diameter of the cylinders had been fixed at 12.7 cm (5 in.) to get the required thrust and the stroke at 2.36 m (93 in.) to get a maximum tilt angle of close to 36 degrees.

The volume of oil for one full stroke is:

$$\text{Vol} = \frac{4 \times \pi \times 12.7 \times 12.7 \times 236}{4 \times 1000} = 119.7 \text{ liters (31.61 G)}$$

With a pump capacity of 113 l/min (30 GPM), the theoretical raising time is:

$$\text{Raising time} = 60 \times 119.7 / 113 = 63.2 \text{ seconds}$$

Experimentally, the raising time was measured at 70 seconds for the table without load.

3.2.3 OTHER HYDRAULIC EQUIPMENTS

The hydraulic schematic diagram given in figure 4, shows all the hydraulic components. The function of each important part is as follows:

The pressure compensated pump with a capacity of 113 l/min (30 GPM) is driven by an internal combustion engine running at 1800 rpm. The pressure regulator is adjusted at 13.8 MPa (2 000 psi).

Flow regulators, adjustable at distance by control cables, are used to vary the raising and lowering speeds from the table control box.

The flow divider is made of four gear pumps with one common shaft. Depending on the exit pressures, each gear set works as a motor to drive the others sets or as a pump to push oil against the highest pressures. Pilot check valves are used to positively block the cylinders at any position because, without them, there might be oil leakage through the flow divider from one cylinder circuit to the others.

A pressure compensated flow regulator is installed on each circuit of the equalization valves EQ1 to EQ4 to assure a constant correction flow whatever the cylinder pressure. The equalization valves are also used to remove residual cylinder pressures at the end of the lowering stroke to make sure each cylinder completely retracts. In order to avoid generation of excessive pressure, should the flow divider work as a pressure intensifier, there is a pressure relief valve on each cylinder circuit.

Hose break valves are directly installed on the cylinder in order to automatically block the cylinder if an oil line is broken. They are used only for safety reason and they do not play any role in normal operation.

3.3 Installation

The hydraulic components are all assembled on a common frame called the hydraulic group; only the cylinders and the velocity fuses are installed on the table itself. Figure 5 shows the hydraulic group.

The user manual (ref. 2) gives the list of all the hydraulic parts along with their technical specifications.

4.0 ELECTRICAL SYSTEM

4.1 Principle of operation

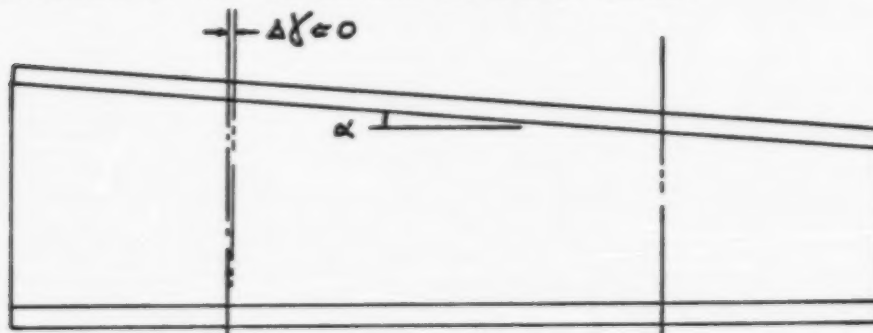
Figure 6 shows the schematic diagram of the electrical system of the tilt table.

4.1.1 UP & DOWN COMMANDS

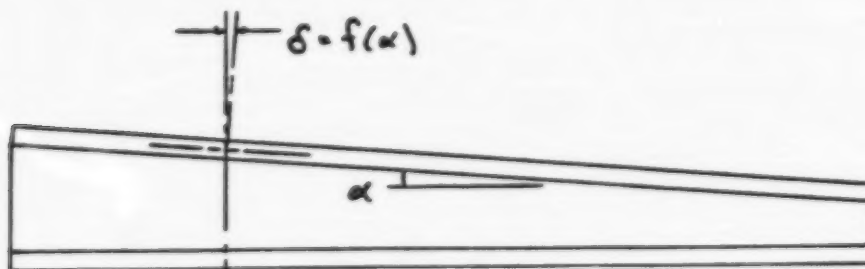
To raise or lower the table the operator must press on and maintain the appropriate push button down; this mode of operation has been selected for safety reasons. Additionally there is an emergency push button the operator can use to cut power if a button blocks or to stop every thing quickly.

4.1.2 LEVEL AND SYNCHRONIZATION CONTROL SYSTEM OF THE PLATFORMS

On each platform there is a system detecting if the two cylinders extend and/or retract simultaneously. This detection system is based on the fact that a longitudinal torsion of the platform brings about a very little inclination of the cylinders as shown below.

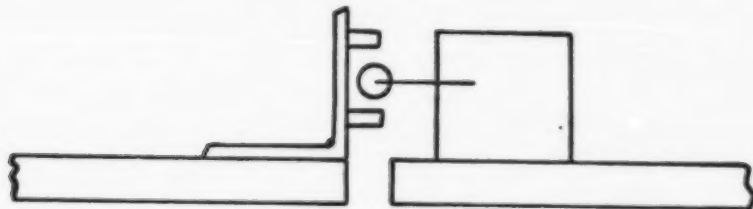


If a needle is attached to the trunnion of the cylinder, so it moves with the platform, the change in the platform longitudinal inclination can be detected by the motion of the needle relative to the cylinder.



With switches fixed to one cylinder and activated by the trunnion's needle, we get a very sensitive system capable of detecting small level variations according to the initial level. Switches act on appropriate equalizing valves until the platform is back to its initial level.

The synchronization of the two platforms is simpler and it is easier to measure their height difference. A double acting switch is fixed to one platform (no 1) and actuators are attached to the other platform (no 2).



If a height difference appears when the table is tilting, the switch detects which platform is higher and it activates the equalizing valves of the two cylinders holding this platform until the height difference reverts to the accepted bracket.

A series of auxiliary switches are installed in a similar way and inform the operator when the longitudinal inclination of a platform or the height difference between platforms exceed pre-established limits.

4.2 Installation

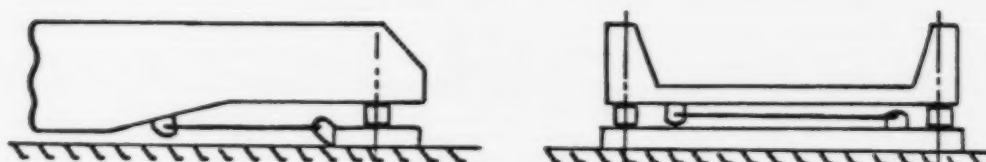
Most of the electrical parts are regrouped in two boxes: the main junction box on the hydraulic group and the control box. Figure 7 shows the general arrangement of the electrical equipment and the wiring lay-out.

The list of all the electrical parts is given in the user's manual (ref. 2) along with the technical specifications.

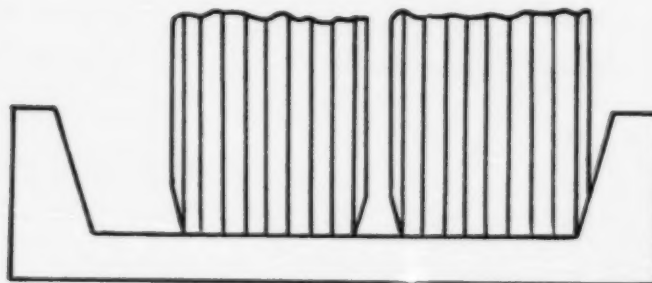
5.0 WEIGHING PADS

5.1 Design

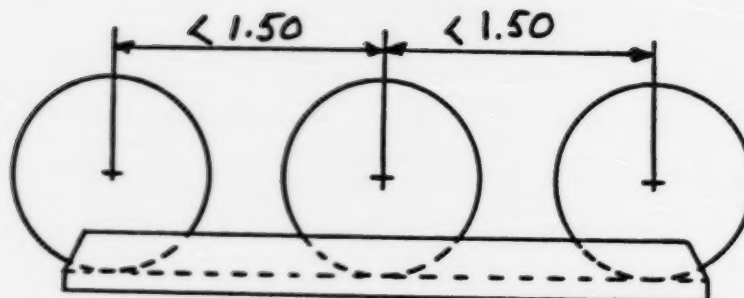
Each weighing pad is basically a small rectangular platform designed to hold the tires of an axle group on one side of a vehicle. This pad is supported by load cells at each corner. The four load cells are installed in such a way that they measure only the loads perpendicular to the top surface of the weighing pad. A series of reaction rods take all the longitudinal and transversal loads. The following sketch illustrate the principle of installation of the cells.



The two longer sides of the pad form a high box beam which avoid slippage of the tire during a tilt test and give the pad excellent stiffness with a relatively low weight.



Each weighing pad measures 3.35 m (11 ft) long and 107 cm (42 in.) wide; the rolling surface is 92 cm (36 in.) wide. Each pad can support a three axle group as long as the axle spacing is less than 1.50 m.



5.2 Load capacity

Each weighing pad is supported by four 11 400 kg (25 000 lb) load cells giving a total capacity of 45 600 kg (100 000 lb) when the load is uniformly distributed. However, the two following conditions should be considered:

- The longitudinal displacement of the load limits the load to the capacity of two load cells because longitudinally, the resultant of the load can be located just on top of two load cells.
- When tilting a vehicle, to the rollover point, the total axle load is transferred to the pad on the low side and moreover, there is often more weight on the cells on the low side of the pad.

We calculated that the maximum load on one pad should be limited to an axle group carrying 30 000 kg; the cells can work up to 150% overload and can tolerate up to 300% overload without mechanical failure.

The technical specifications of the cells and the wiring of each weighing pad are given in the user's manual (ref. 2).

6.0 DRAWINGS

6.1 Drawings of the structure

The structure of the tilt table is detailed in the CRIQ drawings nos:

368-00-00	1 de 2	Table de renversement
368-00-00	2 de 2	" " "
368-01-00	1 de 2	Plate-forme soudée
368-01-00	2 de 2	" " "
368-02-00	1 de 1	Base soudée
368-04-00	1 de 1	Rampe
368-05-00	1 de 1	Fléchette
368-07-00	1 de 1	Attaches de camions et remorques
368-08-00	1 de 2	Boîtier de détection de niveau
368-08-00	2 de 2	" " "
368-09-00	1 de 1	Détecteur
368-00-03	1 de 1	Vis du cric
368-00-04	1 de 1	Pied du cric
368-00-05	1 de 1	Penture
368-00-06	1 de 1	Support du cylindre gauche
368-00-07	1 de 1	Attache du cylindre
368-00-08	1 de 1	Axe du cylindre
368-00-09	1 de 1	Plaque de renfort
368-00-10	1 de 1	Axe 1½" de penture
368-00-11	1 de 1	Support du cylindre droit

6.2 Drawings of the weighing pads

The construction of the weighing pads is fully described in the CRIQ drawings nos:

368-03-00	1 de 3	Plateau de pesage
368-03-00	2 de 3	" " "
368-03-00	3 de 3	" " "

6.3 Electrical drawings

The electrical system is described in the following CRIQ drawings nos:

368-00-02	1 de 3	Schéma électrique
368-00-02	2 de 3	Liste de matériel
368-00-02	3 de 3	Liste de matériel

6.4 Hydraulic drawings

The schematic drawing of the hydraulic system is presented in CRIQ drawing no:

368-00-01	1 de 1	Schéma hydraulique
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CONCLUSION AND RECOMMENDATIONS

The tilt table was built for Transport Canada to run a series of tilt test in the Vehicle Weight and Dimension Study. Even if the latest improvements to the hydraulic and level detection systems had not yet been implemented, the behavior of the table was found to be very adequate. By locating the test vehicle to reasonably distribute the load on each platform, the operators have always obtained a very good synchronization of the cylinders and the difference in the lateral tilt angles has never been more than 1/2 degree.

After these tests, the capacity of the table to support ill-centered loads was improved with the addition of pressure compensated flow regulators on the equalizing valve circuits and with more precise level detectors. It was then proven that, even under extreme load positions and temperatures, each platform keeps its level within 7.5 cm (3 in.) of the base.

Here are some recommendations based on our experience: firstly, the perfect synchronization of many hydraulic cylinders will always be a source of problems and, even if some corrections can be made, we think that the use of long screw jacks (acme threads) will be advantageous; this is a more expensive solution to start with, but they will always be in perfect synchronization and there is no risk one falls down and twists the platforms; secondly, in order to minimize the effects of a bad synchronization of the actuators, the platforms should be built with the actuators located at each end and not at the quarter of the length as on the present table; the structure will end up being heavier but the correct operation of the table will be less demanding on the precision of the actuators. This configuration will also avoid overloading an actuator when the load is close to one end of the platform.

If hydraulic cylinders are retained, double acting cylinders would provide positive lowering of the platforms specially at low temperatures with low loads. The hydraulic group should be located at the center of the table and each hydraulic line should be of the same length in order to get identical response from each cylinder.

During the tests, the table was always operated at its lower speed and we believe it is an error to fit it with a power unit capable of tilting it completely in 60 - 70 seconds. The table was always at a low speed (full stroke in about 135 seconds) and we never used the remote speed adjustment. A system to control the raising and lowering speeds should be simply installed on the hydraulic group and adjusted during the installation of the table.

The table, composed of two sections, is quite easy to move. This configuration could also be used to submit vehicles to torsion by modifying the hydraulic circuit commands specially if the table was pivoted at the center of the vehicle. This means a higher platform, but it would be interesting to fully investigate this concept.

In conclusion, the actual table fills a need and we are confident it will be a very useful test bed for many years.

REFERENCES

- 1- Bédard, Jean T., "Tilt table-User's manual", Transportation Development Centre, Transport Canada, report no TP 7522E, March 1986.
- 2- Sauvageau, Claude, "Vérification de la résistance d'une table de renversement de camion", Centre de recherche industrielle du Québec, report no PRT-85-068, June 1985.

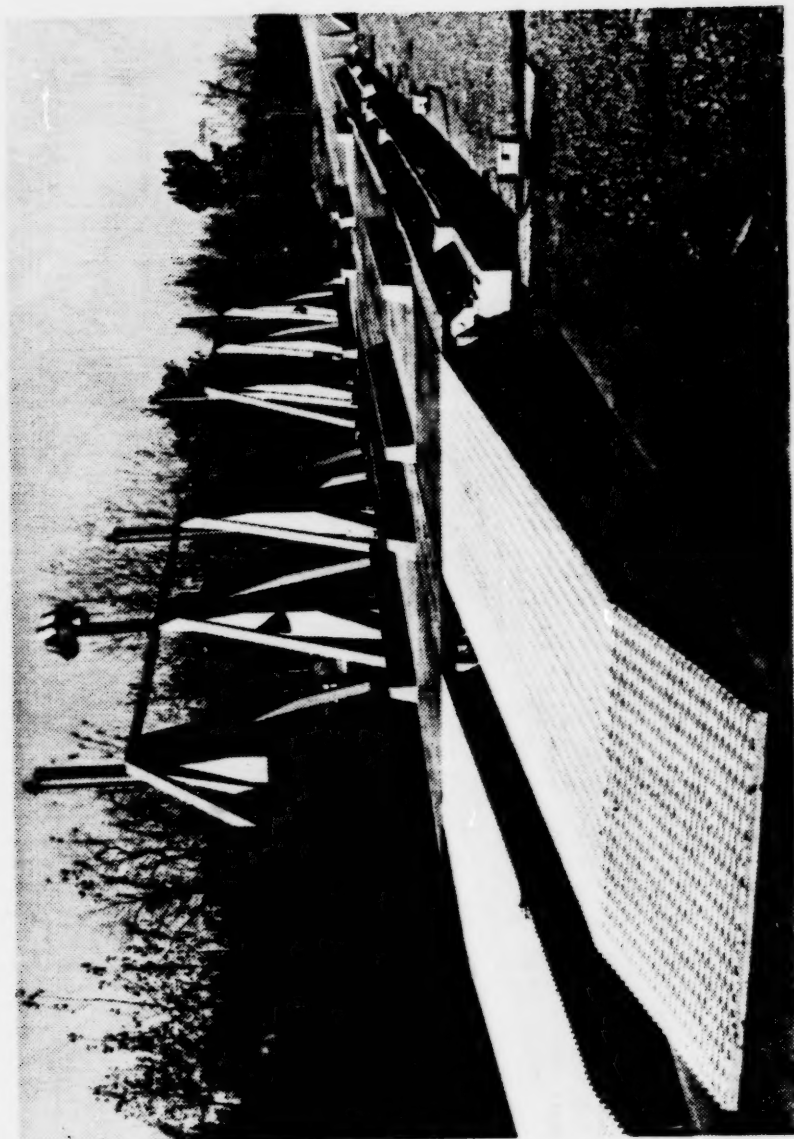


FIGURE 1: TILT TABLE

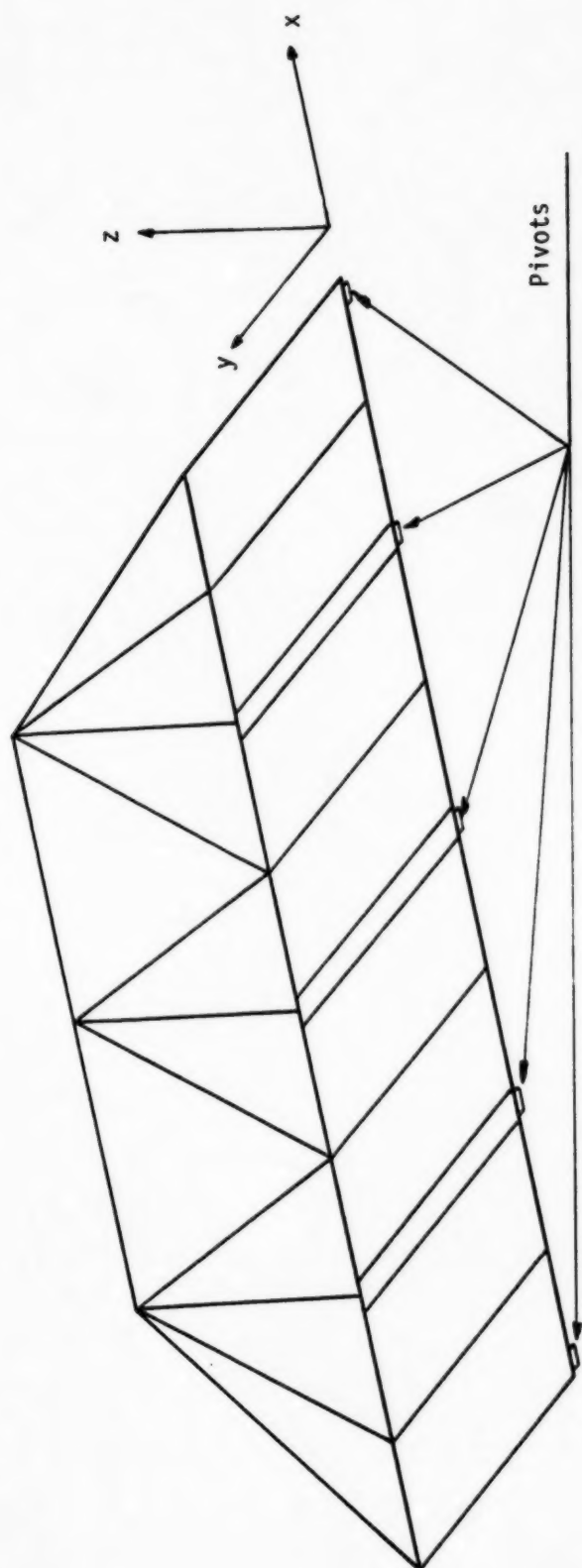


FIGURE 3: Main structure of tilt table

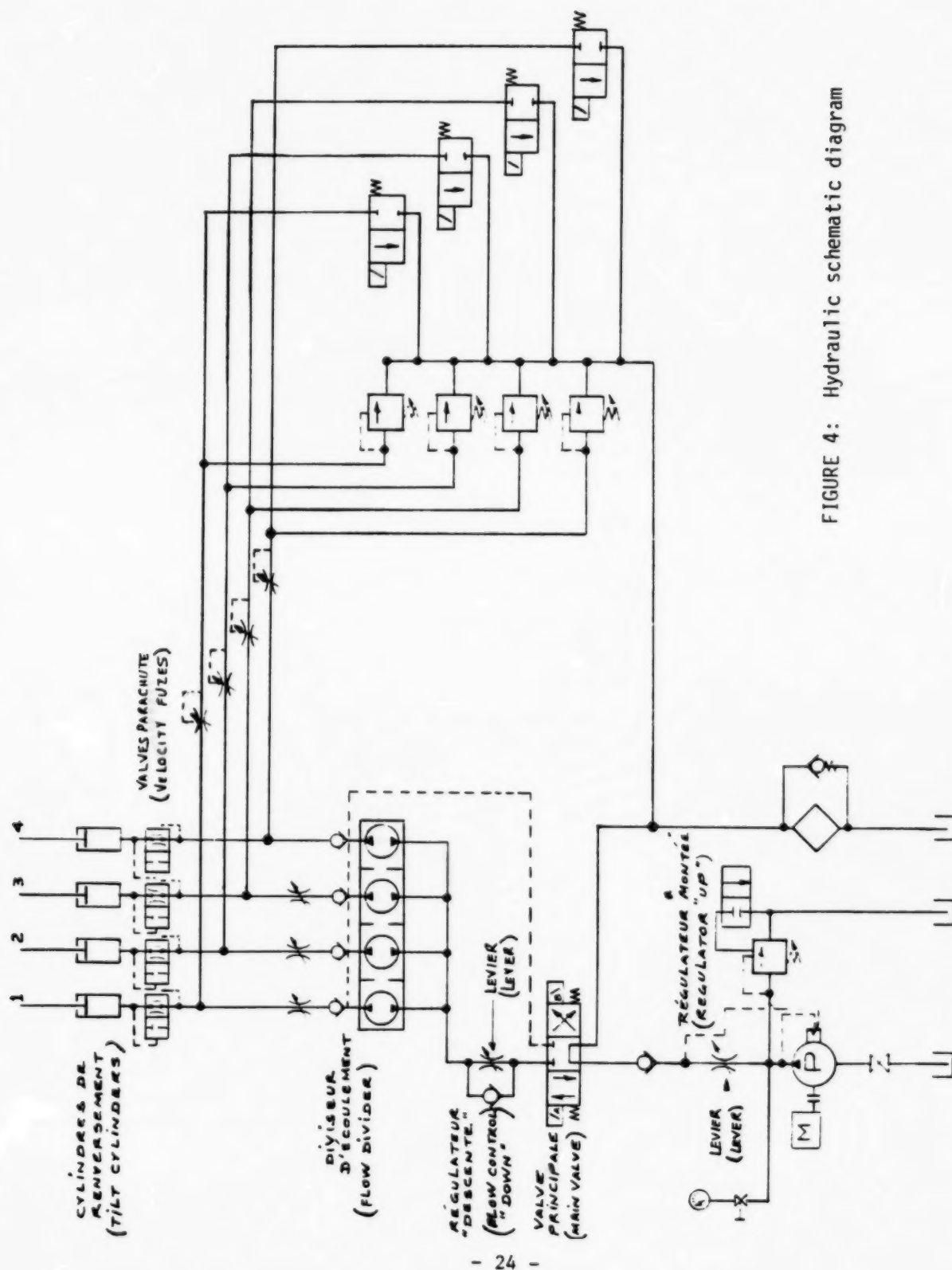


FIGURE 4: Hydraulic schematic diagram

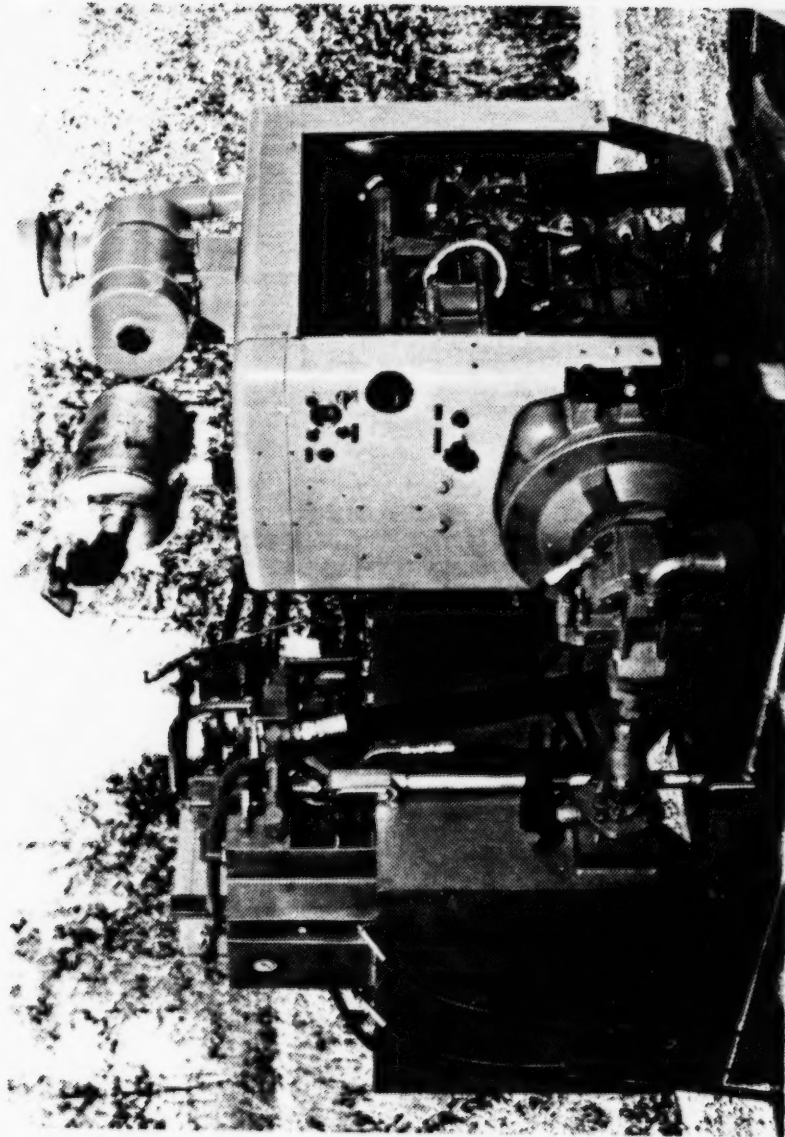
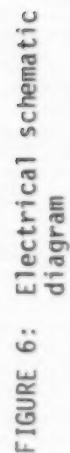
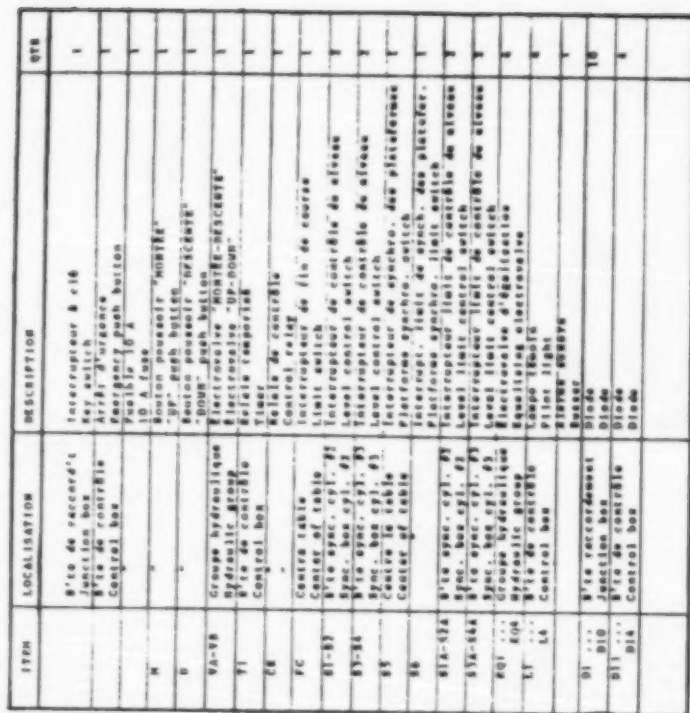


FIGURE 5: Hydraulic group



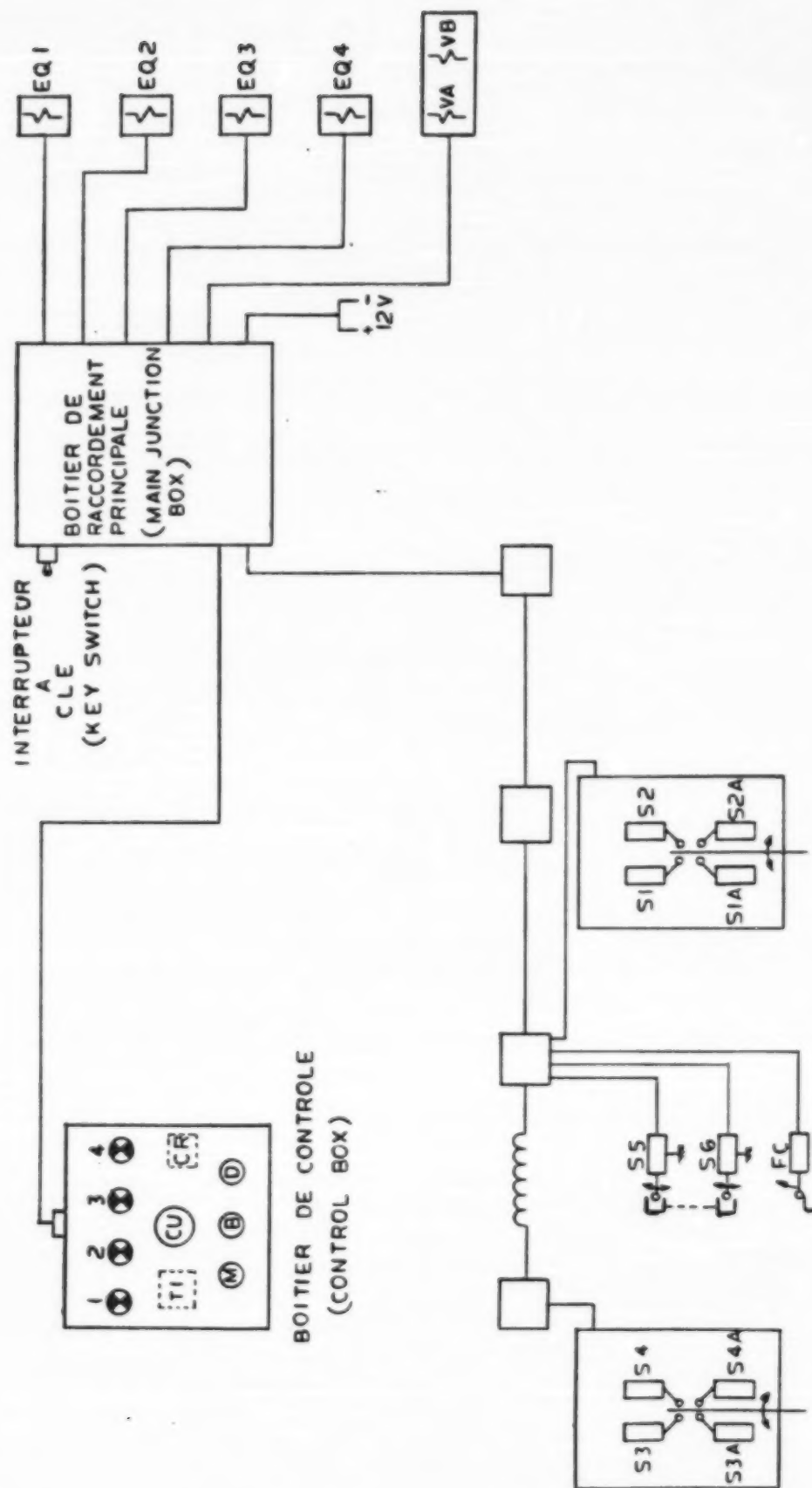


FIGURE 7: Electrical equipment: general arrangement

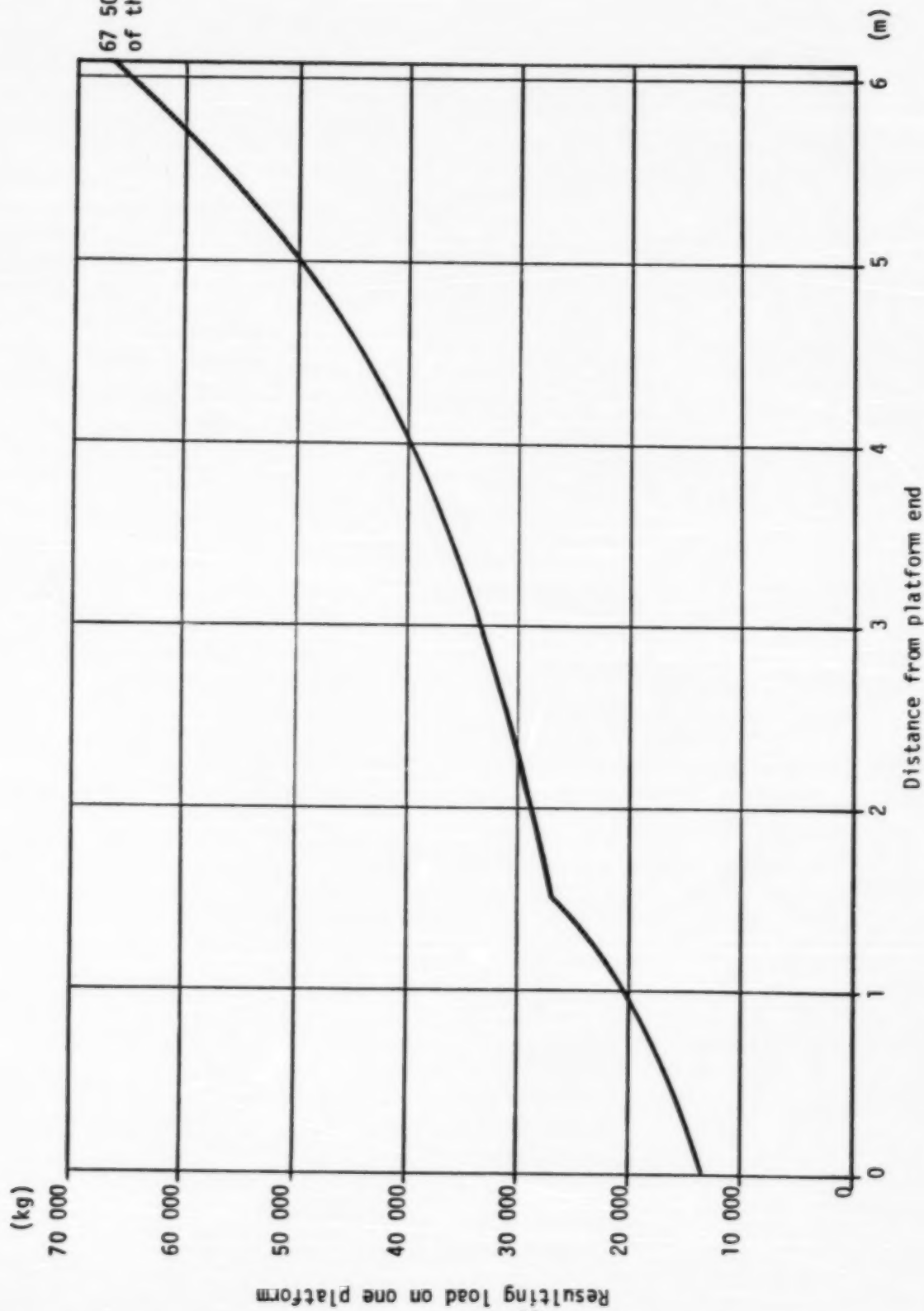


FIGURE 8: Maximum resulting load on one platform according to its position

APPENDIX A

Tilt table

Experimental cylinder pressures vs
table loads

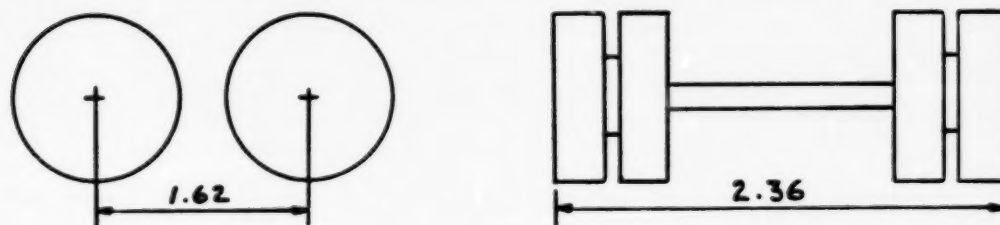


1. DESCRIPTION OF THE TESTS

A pressure gauge was installed directly at the base of cylinder no 1, i.e. the one nearest to the hydraulic group. Pressure readings were taken while the table was tilted from 0 to 5 degrees only because the theoretical maximum pressure is reached at the beginning of the tilt; pressure to maintain the table at 5 degrees was also noted.

The load on the first platform was a semi-trailer with two different loads on its tandem rear axles. These two axles were the only load on platform no 1 and the center of the tandem was located at various longitudinal positions along platform no 1. The table was operated in normal condition with two weighing pads on the high side and one on the low side.

The tandem axles of the test vehicle had an axle spread of 1.62 m (64 in.) and a total axle width of 2.36 m (93 in.); the eight tires were 1100-R-22.5.



2. RESULTS WITH THE TABLE WITHOUT LOAD

With no load on the table, a pressure of 320 psi was noted while tilting over the first 5 degrees; at rest, at 5 degrees tilt, the pressure was 315 psi.

3. RESULTS WITH A LOAD OF 16 100 KG

The pressures recorded during the tilting of the table over the first 5 degrees and at rest, with a load of 16 100 kg on the tandem are as shown in the following table:

<u>Distance from end of the table</u>	<u>Pressure in cylinder no 1</u>	
	<u>Tilting</u>	<u>Stopped at 5 degrees</u>
6' 10"	1220 psi	1100 psi
6' 7"	1120 psi	1000 psi
10'	1090 psi	987 psi
20'	715 psi	679 psi
30'	465 psi	450 psi
36'	190 psi	-

4. RESULTS WITH A LOAD OF 23 500 KG

The pressures recorded during the tilting of the table over the first 5 degrees and at rest, with a load of 23 500 kg on the tandem are as shown in the following table:

<u>Distance from end of the table</u>	<u>Pressure in cylinder no 1</u>	
	<u>Tilting</u>	<u>Stopped at 5 degrees</u>
6' 8"	1600 psi	1390 psi
10'	1396 psi	1265 psi
20'	900 psi	866 psi
30'	430 psi	440 psi
36'	100 psi	170 psi

5. ANALYSIS OF THE RESULTS

5.1 Table with no load

The pressure required to tilt the table over the first 5 degrees was 320 psi. On the other hand, the pressures noted with the loads located at 30 ft should also represent the pressure required to lift the table's own weight because at this position, the external load is centered on the other cylinder and it should have no effect on the instrumented cylinder. In these conditions, the pressures were 465 and 430 psi.

It is difficult to precisely determine the pressure required to tilt the table's own weight because of dynamic effects but a maximum pressure of 425 psi can be retained.

5.2 Estimation of the maximum capacity of the table

Taking into account the two pressure measurements made at 10 ft from table end, i.e. with the load centered with the instrumented cylinder, the two following equations may be considered:

$$\text{Platform weight} + 16\,100\text{ kg} = 1\,090\text{ psi} \times K_1$$

$$\text{Platform weight} + 23\,500\text{ kg} = 1\,396\text{ psi} \times K_1$$

The solution of these two equations shows that the platform weight corresponds to 424 psi in the cylinders and each additional 24,2 kg load centered with a cylinder increases its pressure by 1 psi. With these values, the maximum load the table could support without exceeding 2 000 psi is estimated at:

$$(\text{max pres.} - 424) \times 24,2 \times (2 \text{ cylinders}) \times (2 \text{ platforms}) =$$

$$(2\ 000 - 424) \times 24,2 \times 2 \times 2 = 152\ 557 \text{ kg (335 625 lb)}$$

In a similar way, the results with the tandem at the center of the table allow the two following equations:

$$\text{Platform weight} + 16\ 100 \text{ kg} = 715 \text{ psi} \times K2$$

$$\text{Platform weight} + 23\ 500 \text{ kg} = 900 \text{ psi} \times K2$$

The solution of these equations gives a pressure of 312,5 psi for the platform weight and shows that a load of 40 kg at the center of the platform corresponds to 1 psi in each cylinder. The total table capacity calculated from these values is:

$$(2\ 000 - 315,5) \times 40 \times 2 = 135\ 000 \text{ kg (297 000 lb)}$$

This total load of 135 000 kg or 300 000 lb is retained as the capacity of the table when the loading is uniform, i.e. the load on each cylinder is equal.

5.3 LIMITATIONS

When the resultant of all the loads on one platform is outside of the two cylinders, the closest cylinder has to support more because it has to take a greater share of the platform weight. Under these conditions, the furthest cylinder is supporting less than half the platform weight and at the limit, its pressure may become zero or negative.

Extrapolation of test results for distances of 6'10" and 6'8" indicates that the maximum load at this distance should be limited to 31 300 kg (68 800 lb) if we do not want to exceed 2 000 psi in cylinder no 1. On the other hand, readings for a distance of 36' give a maximum load of 31 650 kg (69 600 lb) in this position in order to not reach negative pressure in cylinder no 1.

Figure 8 gives the maximum load a platform can support. The curve is based on the toughest test cases. This limit is set by the appearance of a negative pressure in the furthest cylinder; at a distance of less than 1.5 m (5 ft) and by a maximum pressure of 2000 psi in the nearest cylinder. From a practical point of view, it is almost impossible to exceed this curve with 10 000 kg axles because the center of a three axle group can hardly be less than 2 meter.



APPENDIX B

Tilt table

Experimental stress measurement
on the tilt table structure

Ten strain gauges were installed on the structure of the tilt table at places where the finite element analysis indicated the highest stresses. Figures B1, B2 and B3 show where the gauges were installed.

Tandem axles, supporting a total load of 16 100 and 23 500 kg were moved along the instrumented platform and the stresses were noted for 0 and 5 degree tilts. The tandem had an axle spread of 1,62 m (64 in); the width of each axle was 2,36 m (93 in) and the 8 tires were 1100-R-22.5.

Test results are given in tables B1 to B4. All the stresses are lower than 10 000 psi while the yield strenght of the material is 36 000 psi or more. Under these conditions, we could have used a tandem loaded with more than three times the 23 500 test load before reaching the yield point. The common 30 000 kg three axle group spread the load over a larger area and this load is expected to give stresses less than 12 500 psi; this represents a safety factor of 2,8 relative to the yield point.

TABLE B1

STRESSES (psi) MEASURED IN THE STRUCTURE
OF THE TILT TABLE

LOAD = 16 100 kg

TILT ANGLE = 0 degree

GAUGE no	DISTANCE OF LOAD FROM PLATFORM END				
	1.70m	3.05m	6.10m	9.15m	10.97m
1	88	-826	-1 563	-708	354
2	6 342	3 097	147	29	-59
3	6 047	5 015	472	0	-30
4	118	-324	855	265	-206
5	-767	-531	-236	-118	0
6	-383	-324	-59	236	324
7	-826	-767	-797	-413	177
8	-2 743	-3 333	-2 389	-914	30
9	767	501	502	-1 504	4 867
10	177	266	885	4 867	3 274

TABLE B2

STRESSES (psi) MEASURED IN THE STRUCTURE
OF THE TILT TABLE

LOAD = 16 100 kg

TILT ANGLE = 5 degrees

GAUGE no	DISTANCE OF LOAD FROM PLATFORM END				
	1.70m	3.05m	6.10m	9.15m	10.97m
1	974	0	-1 180	-207	679
2	6 638	3 540	1 033	561	826
3	6 461	5 546	1 505	590	649
4	-885	-1 328	561	-1 062	-856
5	-1 121	-738	-590	59	-118
6	-826	-649	-59	561	384
7	-1 092	-1 151	-767	-885	59
8	472	148	2 744	4 543	5 664
9	2 242	2 301	2 685	1 357	1 328
10	1 475	1 593	2 773	6 638	5 517

TABLE B3

STRESSES (psi) MEASURED IN THE STRUCTURE
OF THE TILT TABLE

LOAD = 23 500 kg

TILT ANGLE = 0 degree

GAUGE no	DISTANCE OF LOAD FROM PLATFORM END				
	1.70m	3.05m	6.10m	9.15m	10.97m
1	59	-1 032	-2 006	-738	472
2	8 584	4 041	89	-148	-265
3	8 348	6 697	501	-89	-118
4	30	-855	1 180	354	-206
5	1 062	-855	-295	-177	30
6	-560	-442	-177	-59	148
7	-1 298	-1 445	-1 652	-885	-177
8	-3 068	-4 336	-3 274	-501	560
9	738	501	738	-2 773	-2 861
10	118	59	1 475	7 021	4 425

TABLE B4

STRESSES (psi) MEASURED IN THE STRUCTURE
OF THE TILT TABLE

LOAD = 23 500 kg

TILT ANGLE = 5 degrees

GAUGE no	DISTANCE OF LOAD FROM PLATFORM END				
	1.70m	3.05m	6.10m	9.15m	10.97m
1	1 445	-89	-1 475	-324	914
2	9 056	4 572	797	354	649
3	8 938	7 375	1 445	502	531
4	-1 150	-1 888	266	-767	-797
5	-1 445	-826	-502	30	-30
6	-1 092	-560	0	295	177
7	-1 652	-1 357	-1 357	-1 121	354
8	-1 032	-1 003	2 920	5 369	6 225
9	2 183	2 331	3 304	59	413
10	1 416	1 652	3 481	8 939	6 903

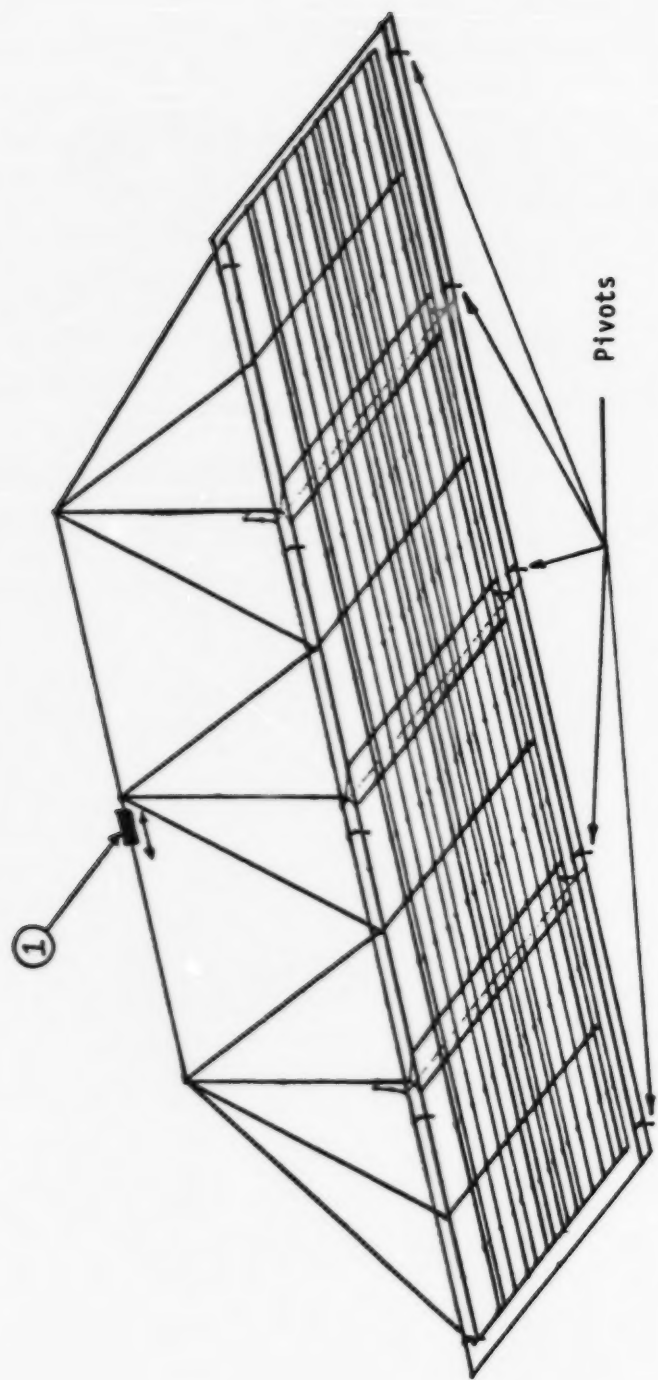


FIGURE B1: Strain gauges localization

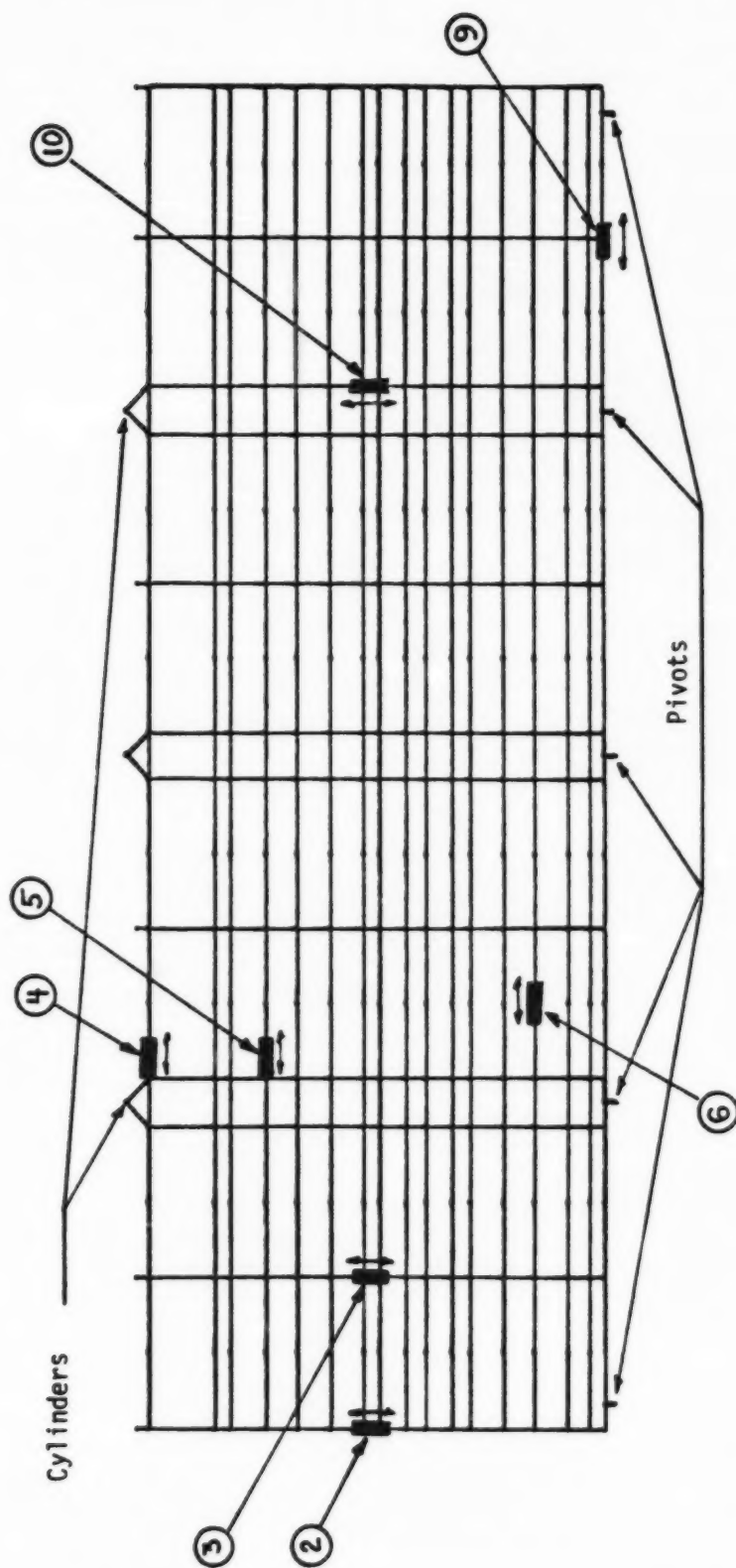


FIGURE B2: Strain gauges localization

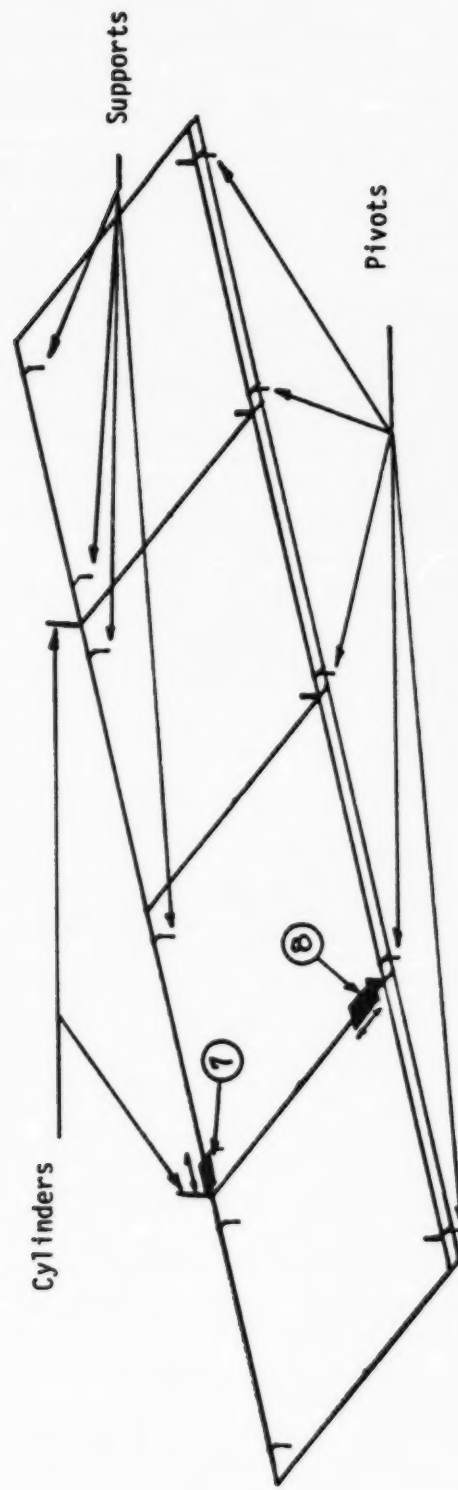


FIGURE B3: Strain gauges localization